ABSTRACT 263

VOLUME-OF-FLUID MODEL COMFLOW APPLIED TO WAVE IMPACT STUDIES

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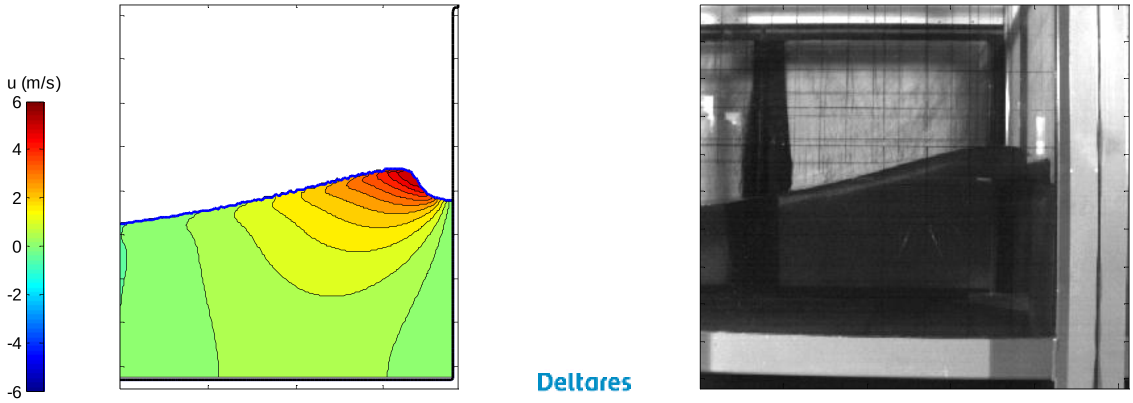

Fig.1 Wave slamming on a vertical wall, just before impact. Left: magnitude of velocity computed by ComFLOW; right: photo taken in Scheldt flume at reduced scale (factor 6 reduced wrt Delta flume)

1. INTRODUCTION

Wave fields in the close vicinity (a few wave lengths) of a coastal structure can be very complex. This is especially the case during extreme storm conditions and/or for complex geometries. Wave breaking, the generation of super- and sub-harmonics, wave set-down and set-up, shoaling and refraction all significantly transform the wave field nearby the structure. Obviously, these wave transformations affect the subsequent wave impacts on the structure. These impacts, on their turn, may cause damage to the structure or even complete failure. Also processes related to wave impacts, like wave run-up on and wave overtopping, are strongly influenced by these wave field transformations. Since the latter are higly nonlinear, analytical models are in most cases inadequate to provide accurate information. Therefore, the majority of studies in this field rely on laboratory experiments in flumes or basins, or on design rules that have resulted from experiments done in the past. However, lab experiments suffer from several deficiencies, such as scale effects, limited reproducibility, and high financial costs. As a result, there is a large interest in a complementary approach: computational models capable of accurate and efficient simulation of the complex wave field near, and the wave impacts on coastal structures. See also the work on Cobras in Losada *et al.* (2008) and references therein. In the present paper, Deltares presents results obtained with the simulation model ComFLOW.

ComFLOW is a 3D Volume-of-Fluid (VOF) model to solve the incompressible Navier-Stokes equations, see Kleefsman *et al.* (2005). From the late nineties on, ComFLOW developments and utilization of the model have been focused on offshore engineering applications: wave run-up and deck impacts (green water) on semi-submersibles and tension-leg platforms; motions of offshore structures to large waves; sloshing in LNG containment systems; air entrapment during wave impacts. These developments have since 2000 been supported by a world-wide consortium of offshore-related companies.

The design of ComFLOW is such that it can be applied not only for offshore engineering, but also for nearshore applications. In the present paper, it is demonstrated that ComFLOW can be successfully applied to coastal engineering problems such as wave impacts.

As a side note, we remark that ComFLOW can be seen as a 3D version of the 2D model Skylla presented in Van Gent (1995) and in Doorn and Van Gent (2003).

2. FUNCTIONALITIES OF COMFLOW

ComFLOW is a Volume-of-Fluid (VOF) method. It solves the incompressible Navier-Stokes equations and the free-surface motion. For each computational cell, the 'VOF'-function indicates which fraction of it is filled with liquid. The occurrence of unwanted 'flotsam and jetsam' (loose droplets that separate from the liquid, being a numerical artefact of the liquid displacement) is reduced by introduction of a local height function in the VOF-function. This allows for accurate simulation of breaking waves. ComFLOW can be applied in 2DV ('flume') and in 3D mode ('basin'). Both a one-phase (water) and two-phase (water and air) option are present, with the latter option being particularly suited to account for the cushioning effect of air entrapment during wave impact. ComFLOW uses simple rectangular (Cartesian) grids, which has several advantages compared to other grid types (e.g. unstructured grids): a more accurate and crisp treatment of the free surface; easier grid generation; simpler and more efficient data structures. The employed cut-cell technique allows for the incorporation of arbitrarily shaped bodies. A staggered positioning of the primary variables (pressure and velocity) on the grid is used, which avoids the need to apply artificial remedies against unwanted pressure-velocity oscillations (so-

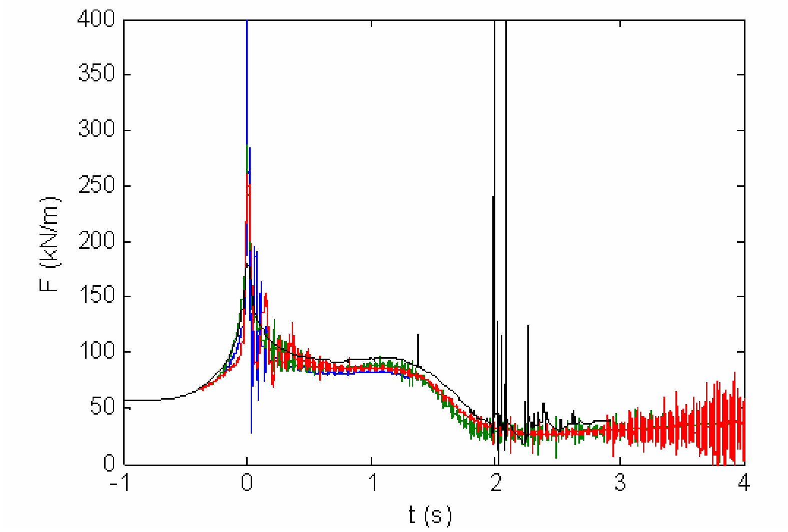

Fig.2 Wave slamming on a vertical wall. Impact forces measured during three realisations of the same experiment (blue, green, red) and computed with ComFLOW (black)

called 2Δx waves).

Research areas to be picked up, in cooperation with the consortium, are: inclusion of a sophisticated turbulence model; improvement of the boundary conditions (extension to 3D; inclusion of currents; better handling of nonlinearities); less dissipative wave propagation (application of higher-order schemes; improved treatment of the free surface); a significant speed-up of the program (local refinement and/or more accurate discretizations; faster sparse-matrix solvers; more efficient implementation including parallelisation).

3. COASTAL APPLICATIONS

In the present paper, two applications with ComFLOW will be addressed.

Wave slamming on a vertical wall

Wave focussing is used in wave slamming experiments executed in the Delta flume of Deltares. A wave train with increasing wave period is generated such that the wave energy and phase are concentrated at one location: the focal point. A vertical wall, equipped with pressure gauges, is positioned at or near the focal point (approx. 240 m from the wave board). A large wave impact occurs when the focussed wave hits the wall, see Figure 1. As boundary condition for ComFLOW, we impose the surface elevation measured approx. 27 m before the wall. Time series of the measured and calculated impact forces are shown in Figure 2, showing a good agreement between experimental and numerical data.

Wave impact on a dike

ComFLOW is used to simulate the impact of breaking waves on an impermeable dike with a 1:3.5 slope. ComFLOW results are compared against experimental data obtained in the Delta flume. The selected time series for the simulation (50 s in length) contains the largest wave that occurred during a one-hour experiment with wave conditions H_s = 1.17m and T_p = 5.40s, and 5m water depth near the waveboard. Figure 3 gives pressure data in a gauge located 0.47m below the still water line, showing a good agreement between experimental and numerical data.

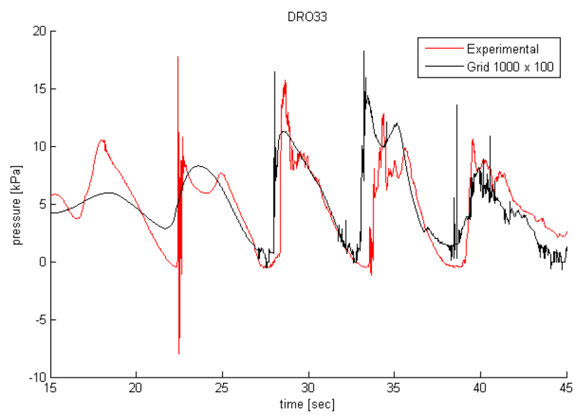

Fig.3 Wave impact on a dike. Pressures measured during the experiment (red) and computed with ComFLOW (black)

REFERENCES

Doorn, N. and M.R.A. van Gent (2003), *Pressures by breaking waves on a slope computed with a VOF model*, Proc. Coastal Structures 2003, Portland, Oregon.

Kleefsman, K.M.T., G. Fekken, A.E.P. Veldman, B. Iwanoski and B. Buchner (2005), *A Volume-of-Fluid based simulation method for wave impact problems*. J. Comput. Phys., 206:363-393

Losada, I.J., J.L. Lara, R. Guanche and J.M. Gonzalez-Ondina (2008), *Numerical Analysis of wave overtopping of rubble mound breakwaters*, Coast. Eng. 55, 47-62

Van Gent, M.R.A. (1995), *Wave interaction with permeable coastal structures*, Ph.D.-thesis, Delft University of Technology.